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Abstract

It is desirable to automatically guide the laser spot onto the effluent plume for maximum IR DIAL system sensitivity. This requires the use of a 2D focal plane array. We have demonstrated that a wavelength-filtered IR camera is capable of 2D imaging of both the plume and the laser spot. In order to identify the centers of the plume and the laser spot, it is first necessary to segment these features from the background. We report a demonstration of real time plume segmentation based on velocity estimation. We also present results of laser spot segmentation using simple thresholding. Finally, we describe current research on both advanced segmentation and recognition algorithms and on reconfigurable real time image processing hardware based on field programmable gate array technology.

Background

The LANL CALIOPE IR camera system consists of a manually aimed telescope, a manually positioned filter wheel, and an Amber Proview Imaging System. The Amber system is a LWIR 256x256 focal plane array that operates in snapshot mode with 12 bit sampling, variable sampling times, digital output at up to 150 Hz (for full array readout), and RS-170 video output at 30 Hz. Nemzek (these proceedings) has demonstrated that this system is capable of imaging both the effluent plume and the laser spot. The IR camera system is currently being upgraded with an acousto-optic tuneable filter to allow real time narrow band frequency selection. It is also being upgraded with computer controlled telescope mounts for automatic pointing.

The Deployable Adaptive Processing Systems (DAPS) Project is sponsored by DOE NN-20 to develop, functionally test, and environmentally test prototype hardware systems to do adaptive event recognition and processing for a variety of applications, including small satellite, airborne, and ground-based nonproliferation efforts. DAPS specializes in building deployable hardware for extracting information from high speed data streams such as are produced by the IR camera system. DAPS provides prototype, proof-of-concept information extraction systems to other projects. These prototype systems either are deployable or have a clear engineering path to deployable systems. The deployed systems are funded by the sponsoring project.

Rationale and Objectives

There are several reasons to replace the present single detector focal plane of the LANL CALIOPE systems with a 2D focal plane array. A primary advantage of 2D arrays is that they have essentially the same sensitivity per unit area as single detectors but the capacitance (and hence noise) of a single pixel is significantly less than that of an entire detector. If the entire 2D array response must be summed and the laser spot does not fill the array, there is no advantage, but if only those pixels illuminated by the returning laser spot are summed, the net result is an increase in signal to noise ratio.

A second advantage of a 2D focal plane array is that the requirement to maximally fill the focal plane with the laser return is relaxed, making the system less sensitive to alignment errors and to jitter. Finally, incorporation of a 2D focal plane array to a DIAL system has the advantage that "peripheral" vision is added to the laser "fovea", making target recognition including plume detection easier to achieve.

Thus, the shared goal of both DAPS and CALIOPE is to use the IR camera system as input to a DAPS prototype system that autonomously and in real time (1) finds the laser spot, (2) finds the plume, and (3) generates control signals that steer the laser spot onto the plume. It is desirable that "find" be as close to "recognize" as possible in order to minimize errors in actual field conditions; however, "find" at this point effectively means "estimate a set of features (size, speed, texture, etc.) that uniquely characterize the target in a given scene".

Initial Approach and Results

The initial algorithms chosen for field demonstration were simple and conservative in order to minimize implementation costs and maximize processing throughput. The laser spot typically is brighter than anything else in the scene, so simple intensity thresholding was tried. Thresholding segments the laser spot from the background and centroiding the result determines the laser spot location.

The plume may or may not be brighter than the surroundings, so intensity thresholding is not appropriate. However, the plume typically is in motion, so velocity estimation followed by velocity thresholding and centroiding was tried. There are many ways to estimate velocities of objects in time sequences of images. We tried two different methods. The first method used standard digital signal processing techniques. After convolving the video frames with a spatial low pass filter, a sequence of frames (typically a few tens of frames) was temporally bandpass filtered. Following velocity thresholding, a final spatial median filter was applied. Figure 1 shows this algorithm applied to a power plant steam plume imaged with a standard commercial video camera.

The second method tried was optical flow[1]. This is a simple, parallel, biologically motivated technique with both digital[2] and analog[3] hardware implementations. This method derives from the assumption that motion in images is smooth; i.e., that motion is exact up to at least first order in a Taylor series expansion. The algorithm iteratively adjusts velocity estimates at each pixel in order to drive DI/Dt to zero according to:

Pick a gain value α (should be small).
Initialize v_x and v_y estimates at each pixel.
For each frame:
1. Estimate dI/dx and dI/dy for each pixel using convolutions.
2. Estimate dI/dt for each pixel using frame differences.
3. Form $DI/Dt = dI/dt + (vx * dI/dx) + (vy * dI/dy) = \varepsilon$
4a. Update v_x according to $(v_x)_{new} = (v_x)_{old} - (\alpha * \varepsilon * dI/dx)$
4b. Update v_y according to $(v_y)_{new} = (v_y)_{old} - (\alpha * \varepsilon * dI/dy)$

Repeat.

The difference in centroids of the laser spot and the plume is the control signal used to steer the DIAL system.

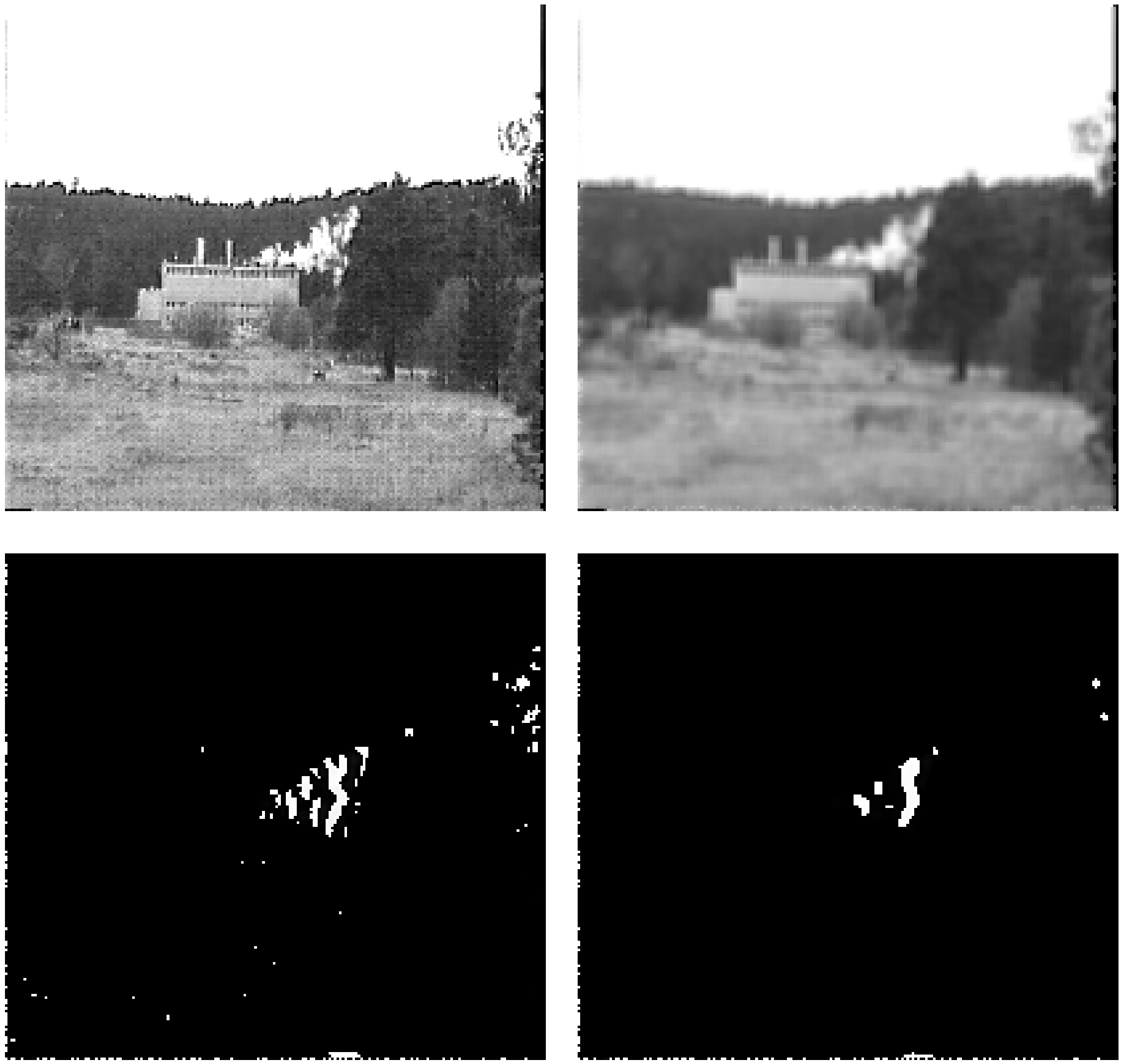

Figure 1. Motion estimation using spatial and temporal filters. The raw image (top left) is first spatially low pass filtered (top right), then temporally filtered (bottom left), and finally median filtered (bottom right). The resultant center of mass is the plume location.

As mentioned earlier, the IR camera data is accessible via either standard RS-170 analog video or a high speed parallel digital port. Because of the short timeline and existing resources, the DAPS prototype system was based on commercial VME products and used a framegrabber to access the IR camera video link. The hardware setup is shown schematically in Figure 2.

The first velocity estimation method used processing modules onboard the framegrabber to do both spatial lowpass and median filtering. Temporal bandpass filtering was done by the digital signal processing (DSP) board. Software was written in C running under VxWorks. The optical flow algorithm was implemented on a CNAPS parallel processor array (256 processors/board) using the MAVIS software development environment.

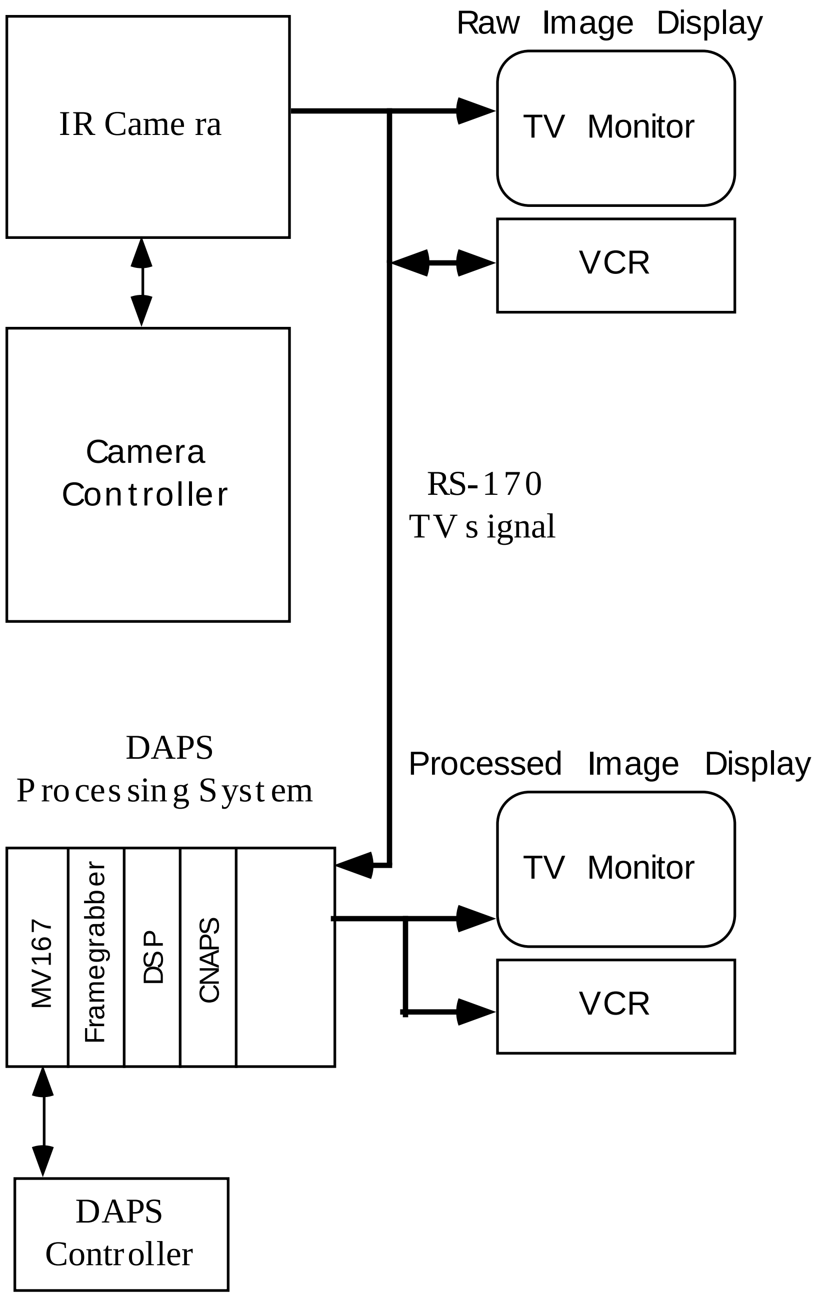

Figure 2. Block Diagram of DAPS Prototype IR Camera Processing System

Current Research

The prototype IR camera and DAPS processing system was fielded successfully in 1996. As a result, the camera and processing system are being upgraded to produce a deployable system in 1997. Algorithm research continues on both laser spot and plume recognition. The LWIR laser spots are highly speckled, so morphological processing (median filtering, gray scale dilations and erosions, etc.) is being investigated. The plumes move in the images, but so do people, cars, dust devils, etc., and turbulence is frequently present. Thus, velocity thresholding is not completely satisfactory. Texture is another feature that can be estimated rapidly and efforts are underway to apply texture estimation to the observed imaged sequences.

The choice of the RS-170 link to the camera is not optimal. It is preferable to interface directly to the high speed digital parallel link. Efforts are underway to develop that interface. This will allow the DAPS processor to accept data from the IR camera as fast as it can be produced, which immediately exceeds the VME bus bandwidth. In an effort to remove this bus bandwidth bottleneck and supply more simple, integer, and parallel processing such as is required for optical flow calculations, DAPS is investigating field programmable gate array (FPGA) technology as the interface and front end processor for the camera. This technology offers dedicated high speed parallel paths and reconfigurable computing - the ability to run different algorithms on the same hardware by downloading different configuration files to the FPGAs.

Conclusions

The DAPS collaboration with CALIOPE has shown initial success. A prototype system using the IR camera and a VME data acquisition system has demonstrated proof-of-principle capability for identifying the laser spot and the effluent plume. Upgrades to both hardware and software should be able to provide an automatic system capable of steering the DIAL system onto a given plume with potentially greater signal to noise ratios than can be expected from single detector systems. Further, advances in array fabrication and VLSI technologies offer the promise of "smart" focal planes in the near future.

References

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